Space weather and critical infrastructures: Activities at the EC's Joint Research Centre

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The risk of natural-hazard impact on critical infrastructures is increasing:

+ More hazards

- Climate change
- Greater industrialisation

+ Higher vulnerability

- Growing development in exposed areas
- Development of new and vulnerable technologies
- Increasingly complex and interconnected society

→ To increase society's resilience a better understanding of hazards, vulnerabilities, interdependencies and potential consequences is needed.

EU Policy context

Directive 2008/114/EC

Council Directive of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection

JRC SW activities

1) Raise awareness of space-weather risks among European stakeholders
(SWAD, SW & PG WS, *planned*: financial sector)

2) Understand the space weather **hazard**, the **vulnerability** of CI and possible **consequences** on society: risk to infrastructure, risk to provided service, risk of cascading effects

→ Analysis of space-weather impact on the European power grid (including interdependencies + impact on society)

→ Impact assessment of space weather on GNSS services (ionospheric scintillation)

How vulnerable to space weather are critical infrastructures in Europe?

→ raise awareness of the problem among the different stakeholders

Space-weather awareness dialogue (SWAD): 25-26 October, 2011, Brussels, Belgium

http://bookshop.europa.eu/en/the-space-weather-awareness-dialogue-pbLBNA25016/


JRC Scientific and Technical Reports

The Space-Weather Awareness Dialogue: Findings and Outlook

An event hosted by the European Commission's Joint Research Centre and co-hosted by the Directorate-General Enterprise and Industry
25-26 October, 2011, Brussels, Belgium

Elisabeth Krausmann

JRC EUROPEAN COMMISSION

EUR 25016 EN - 2011

Severe space weather events – Understanding societal and economic impacts, A Workshop report, National Research Council, USA, 2008

SW % power grid: potential worst-case consequences:

+ Extensive damage or failure due to geomagnetically induced currents (GIC)

+ Damage to or failure of high-voltage transformers (manufacture times of up to 12 months)

+ Collapse of grid due to cascading failure

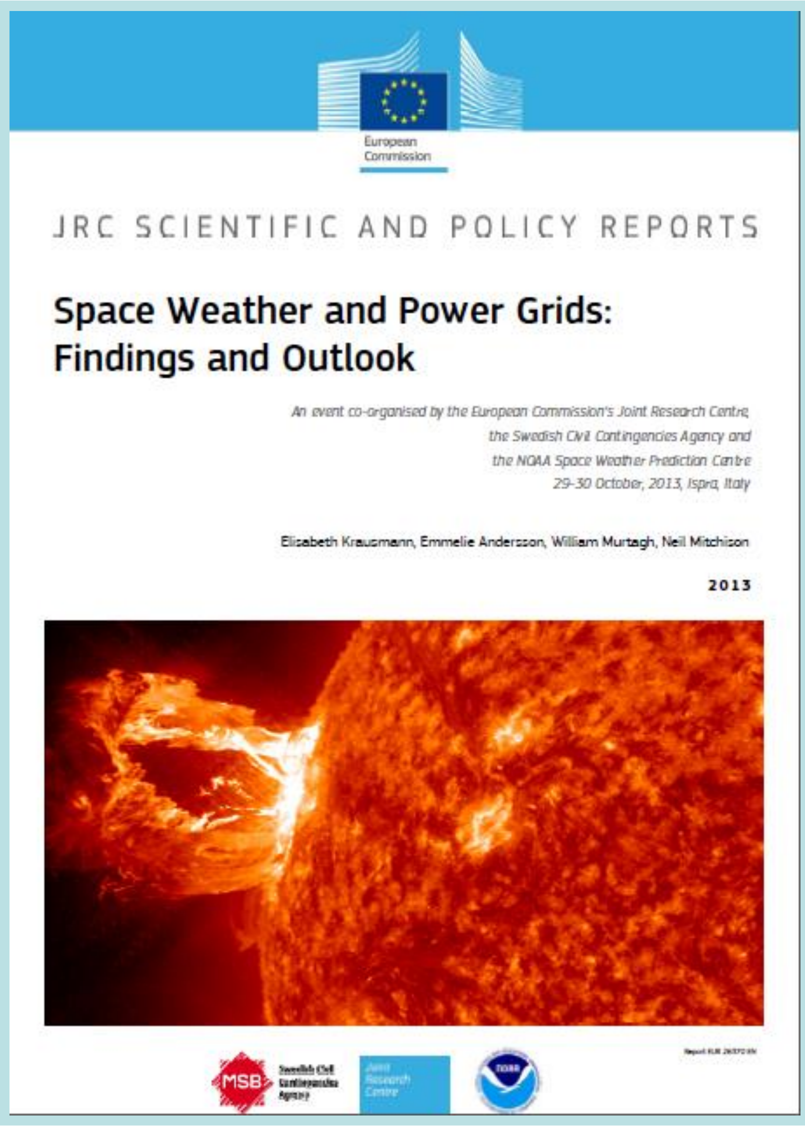
→ without electricity, disruption of communication, transport, banking, distribution of potable water, lack of refrigeration for food and medication, etc.

- **Estimated societal/economic costs: 1-2 trillion $US in the first yr, time to full recovery: 4-10 yrs**

How vulnerable is the power grid in Europe to space weather?

→ launch dialogue and knowledge transfer between authorities, regulators and operators

Space weather & power grid WS:
29-30 October, 2013, Ispra, Italy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JRC SCIENTIFIC AND POLICY REPORTS

Space Weather and Power Grids: Findings and Outlook

An event co-organised by the European Commission's Joint Research Centre, the Swedish Civil Contingencies Agency and the NOAA Space Weather Prediction Centre
29-30 October, 2013, Ispra, Italy

Elisabeth Krausmann, Emmelie Andersson, William Murtagh, Neil Mitchison

2013

http://bookshop.europa.eu/en/space-weather-and-power-grids-pbLBNA26370/

Swedish Civil Contingencies Agency

European Commission

Joint Research Centre

Swedish Civil Contingencies Agency

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Outcome I

- SW risk awareness is increasing.
- SW predictability is still limited and relies on data from ageing satellites.
- In some countries, models and tools for GIC prediction and grid impact assessment have been developed but equipment vulnerability models are scarce.
- Some countries have hardened their power grids to moderate SW.
- Vulnerability of grids to extreme SW is less conclusive and requires assessment.
- In the US new standards for power-grid operations are being introduced to better meet the SW challenge.

E.Krausmann, E. Andersson, W. Murtagh, N. Mitchison, Space weather and power grids: findings and outlook, EUR 26370 EN, 2013

Outcome II

- <u>Interdependencies</u> need to be considered but are not routinely assessed.

- Effective <u>risk communication</u> is required to bridge the gap between science and policy.

- <u>Emergency planning</u> for severe SW needs to consider the full range of potential impacts on CI.

- <u>International cooperation</u> is required to cope with the space-weather threat as response capabilities may be beyond the capacity of individual countries.

- European grids appear less vulnerable to GMD events but this needs verification

E.Krausmann, E. Andersson, W. Murtagh, N. Mitchison, Space weather and power grids: findings and outlook, EUR 26370 EN, 2013

Recommendations

SCIENCE

Improve SW predictability

Enhance forecasting capabilities to provide regional information to operators

Identify benchmark GMD events

Build impact models for grid components under worst-case conditions

Develop integrated RA methodologies and tools incl. interdependencies

OPERATORS

Increase awareness of risks associated to SW

Identify vulnerabilities in the system

Assess changes to overall vulnerability due to implementation of new technological developments

Harden the system

Prepare response plans in case of an alert

AGENCIES (areas for further study)

CI vulnerability assessment to severe SW and inclusion in overall risk and resilience assessment

Mechanisms to share SW alerts with all stakeholders (information sharing capability)

Protocols to ensure consistency in prediction of timing and intensity by different providers

Development and testing of all-in emergency plans

Identify possible further measures to protect the power grid and ensure service availability

E.Krausmann, E. Andersson, W. Murtagh, N. Mitchison, Space weather and power grids: findings and outlook, EUR 26370 EN, 2013

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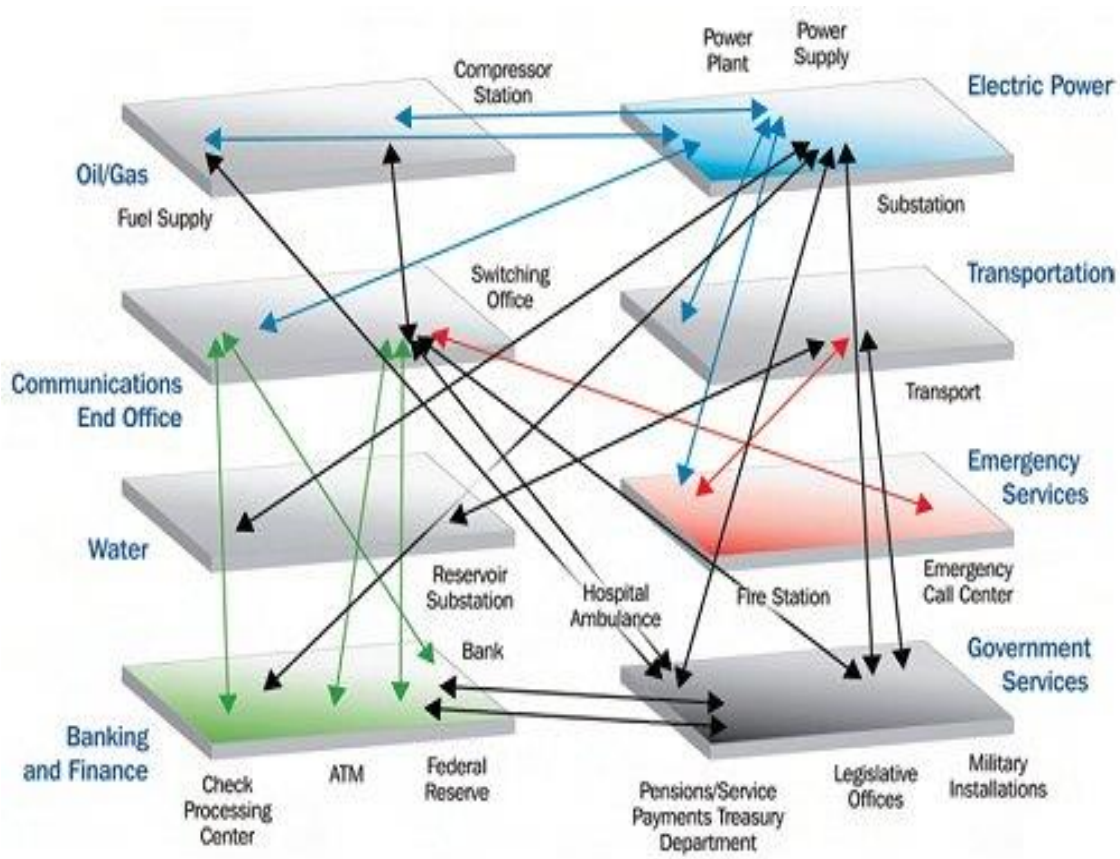
Space weather impact on power grids: open issues

- Assessment of the vulnerability of the power grid with respect to Carrington-type events

- Space weather impact on society: interdependencies between infrastructures



http://www.dhs.gov/xprevprot/programs/editorial_0827.shtm

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Vulnerability analysis perspectives

- **Global vulnerability analysis: consequences of strains of increasing magnitude on the system**

- **Critical component analysis: contribution of components or set of components to the system vulnerability**

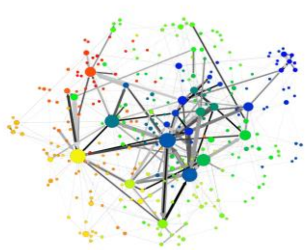
- **Geographical vulnerability analysis: spatially oriented vulnerabilities**

Vulnerability analysis of power grids to GICs:
a Complex Network Approach

Structural Strain

Functional Strain

Structural Model



Input

Functional Model

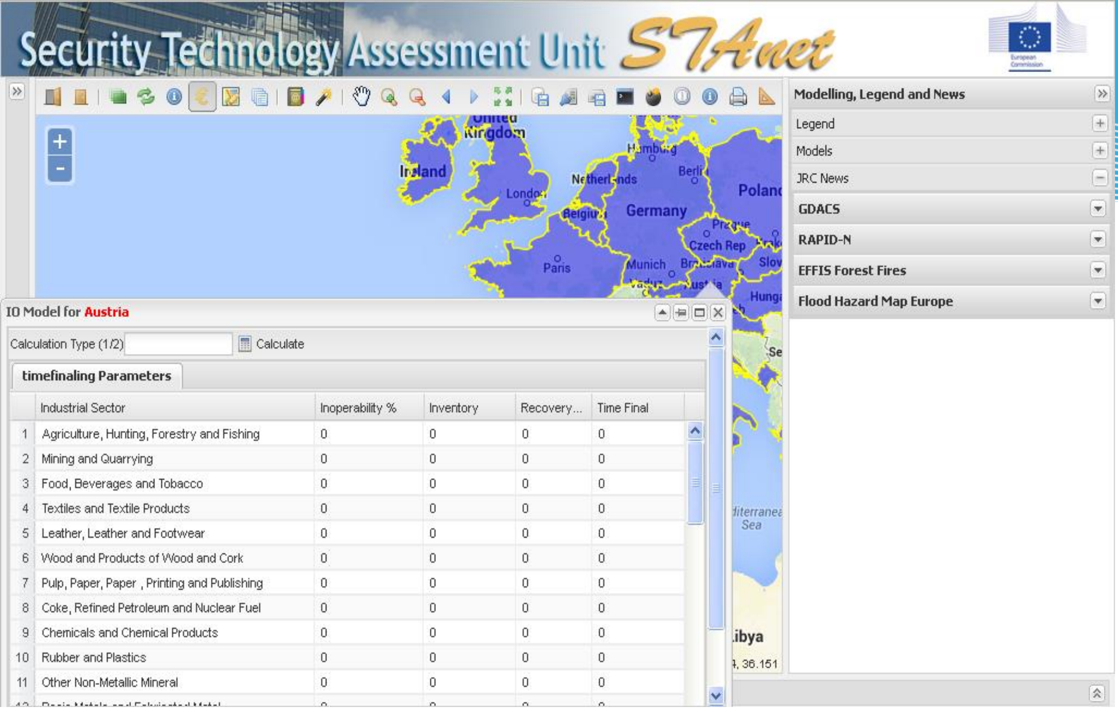
$$I = (U+YZ)^{-1}J$$

[1-4]

Consequences

Cascading effects

[1] M. Lehtinen and R. Pirjola, Annales Geophysicae **3**, 1985 – [2] R. Pirjola, Earth Planets Space, **61,** 2009 – [3] A. Viljanen et al, J. Space Weather Space Clim. **2**, 2012 – [4] D.H. Boteler, PES Conference Proceedings, IEEE, 2013



Interdependencies

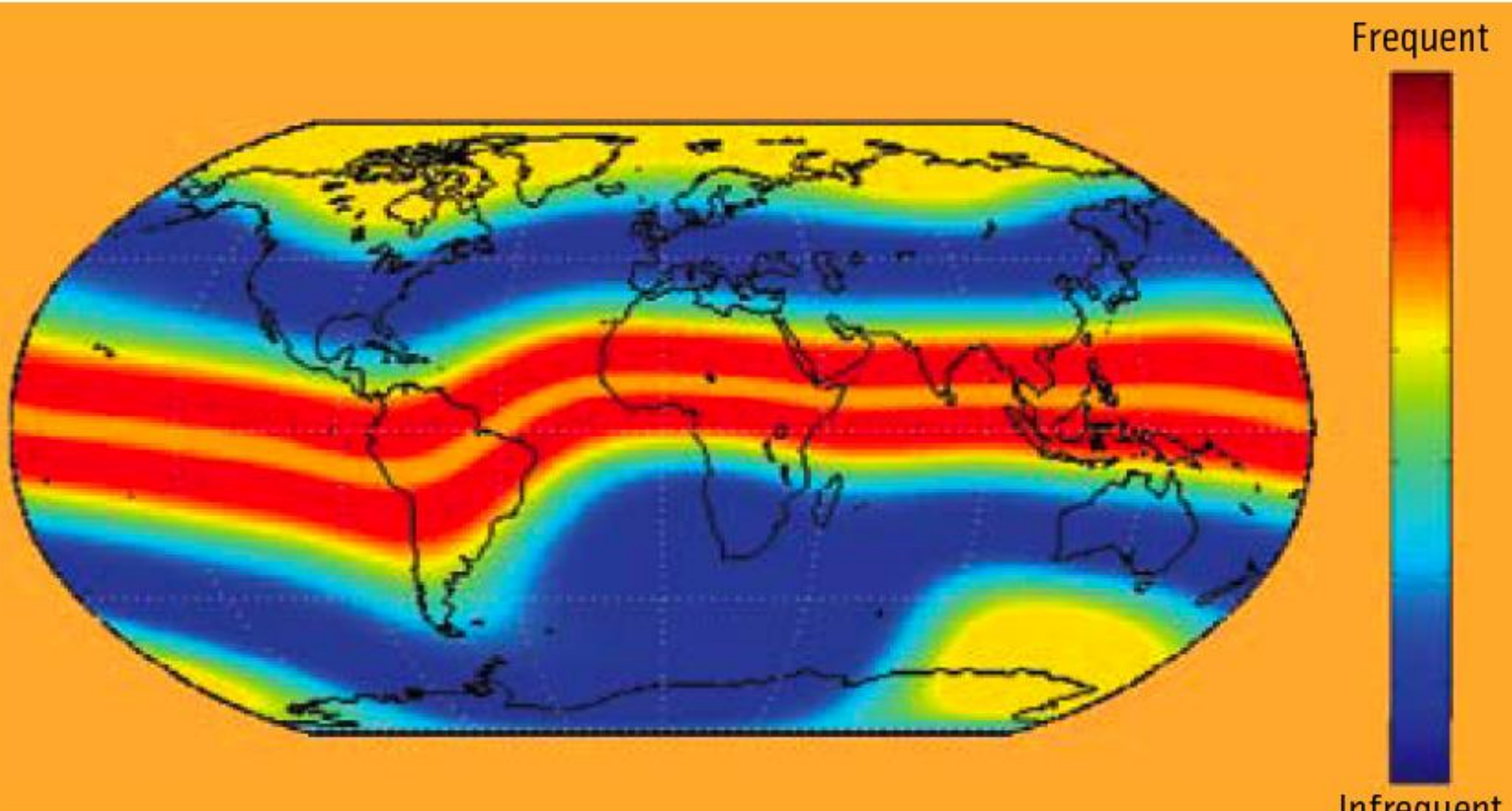
Between sectors (economic impact)

Between infrastructures

(e.g. coupling of power grid model with telecom model)

G. Giannopoulos, I. Azzini, M. Didò, F. Lana, **GR²ASP**

Ionospheric scintillation



P. Kintner et al., GNSS and ionospheric scintillation, InsideGNSS, July/August 2009

FIGURE 1 Scintillation map showing the frequency of disturbances at solar maximum. Scintillation is most intense and most frequent in two bands surrounding the magnetic equator, up to 100 days per year. At poleward latitudes, it is less frequent and it is least frequent at mid-latitude, a few to ten days per year.

Scintillation prediction

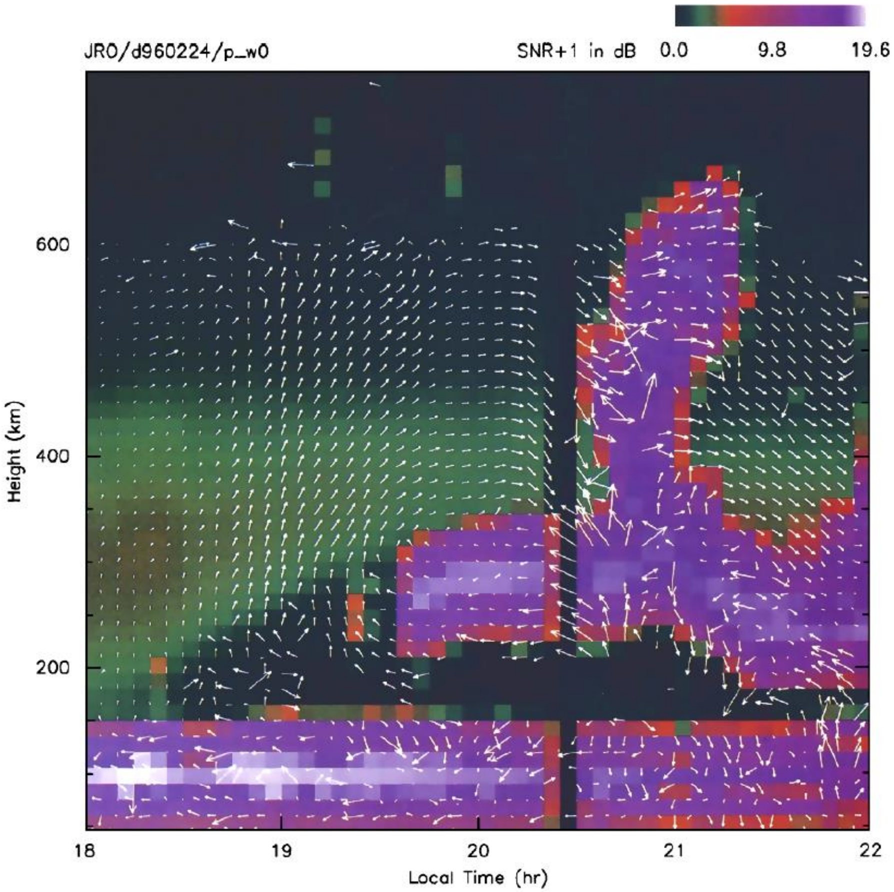
Post sunset plasma drifts

A plasma drift vortex forms post sunset at around 225 km and 20:00 LT.

To the east of the vortex strong upward vertical drifts are observed associated with PRE → plasma irregularities

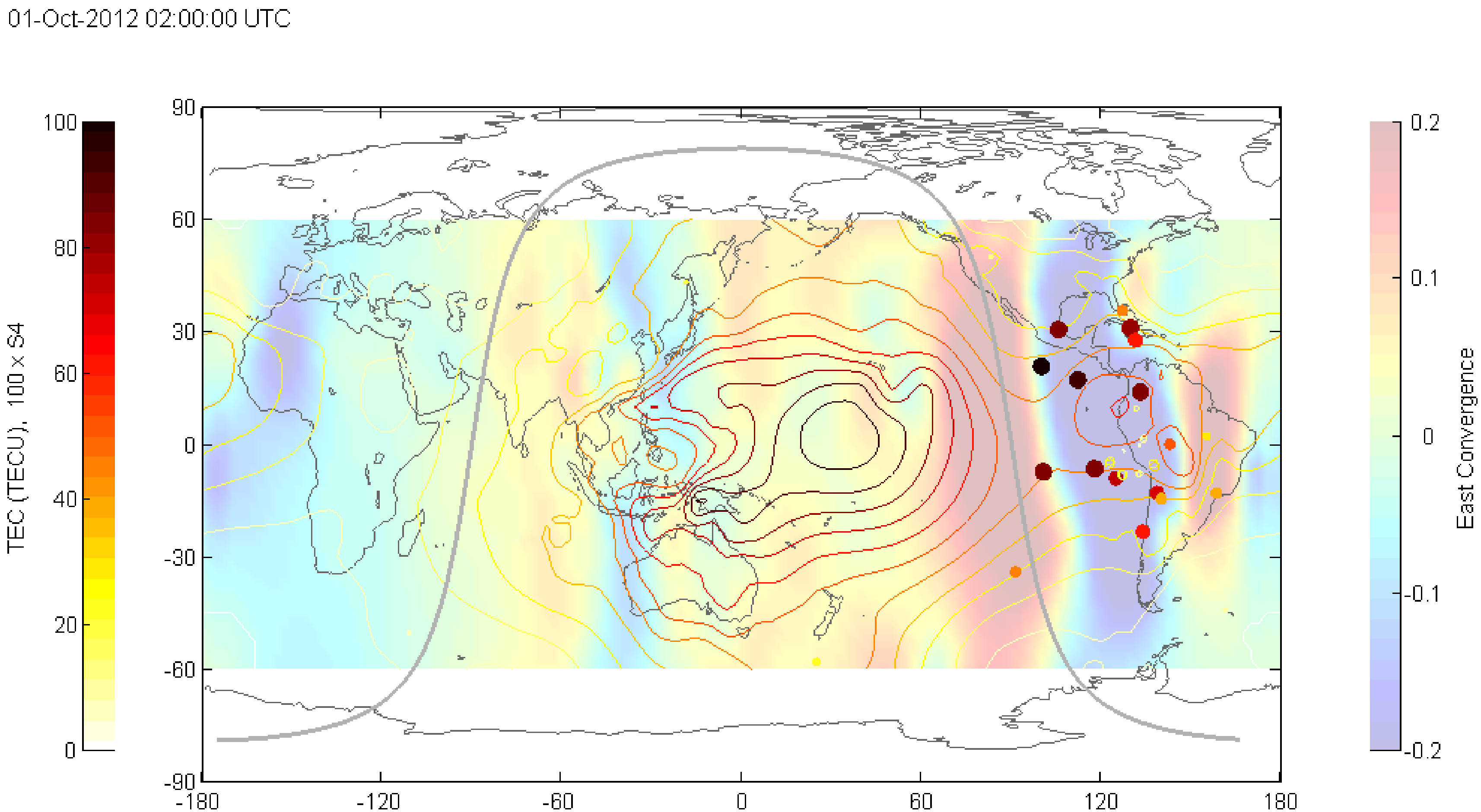
FIRST Model (NOAA)

Ionosonde measurements of the increase in the ionospheric peak height → proxy for PRE which correlates to subsequent scintillation



Plasma drifts observed at Jicamarca

Alternative method



Plasma divergence associated with the post-sunset plasma drift vortex obtained from tomographic reconstructions. Points show S4 scintillation observations from the COSMIC satellite constellation

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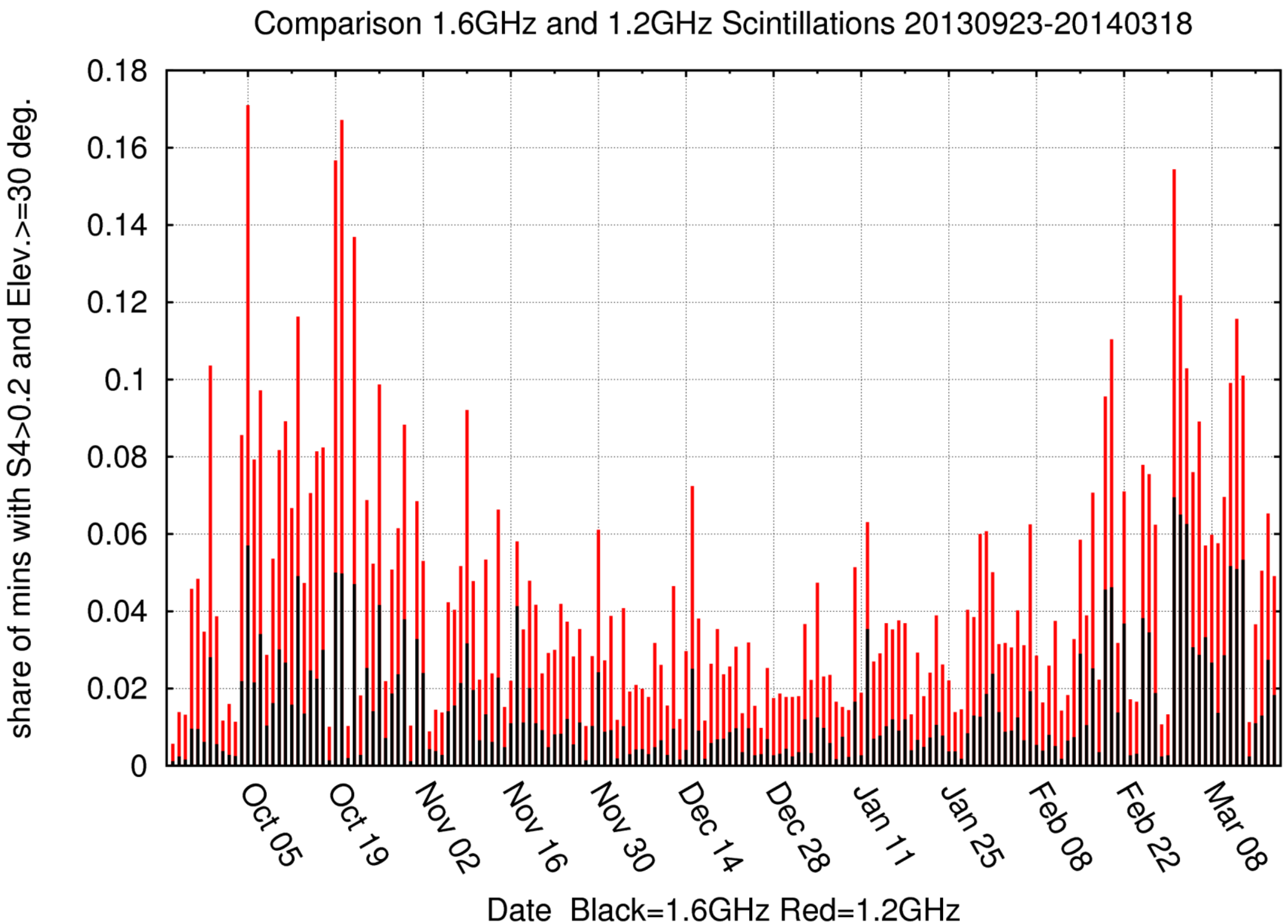
JRC monitoring station Jicamarca, Peru

GPS/L1 receiver since April 2012

GPS/GALILEO/GLONASS L1/L2c/L5/E5 since Sept. 2013

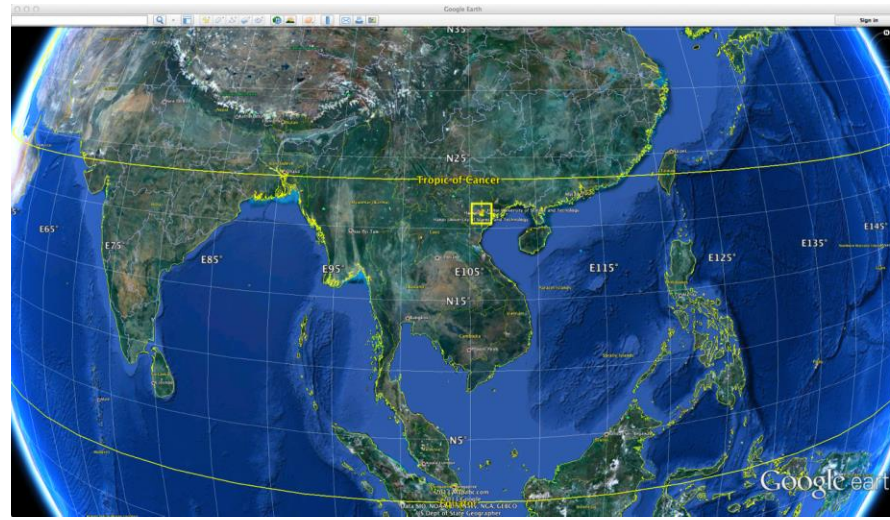
USRP IF Grabber
- time control

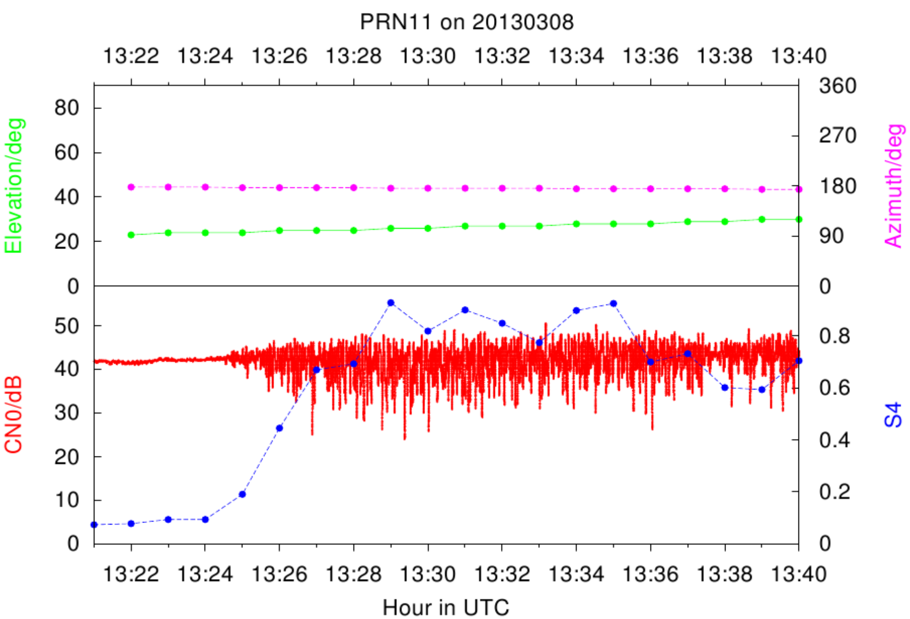

Comparison 1.6GHz and 1.2GHz Scintillations 20130923-20140318
share of mins with S4>0.2 and Elev.>=30 deg.
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
Oct 05
Oct 19
Nov 02
Nov 16
Nov 30
Dec 14
Dec 28
Jan 11
Jan 25
Feb 08
Feb 22
Mar 08
Date Black=1.6GHz Red=1.2GHz

Hanoi, Vietnam

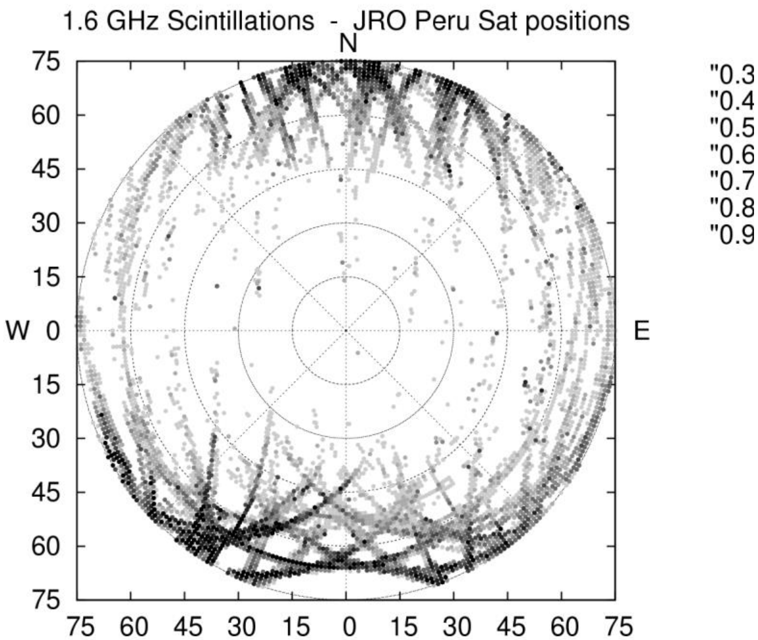
Partners ISMP Turin, NAVIS/HUST, ESA

- USRP IF Grabber
- Time control

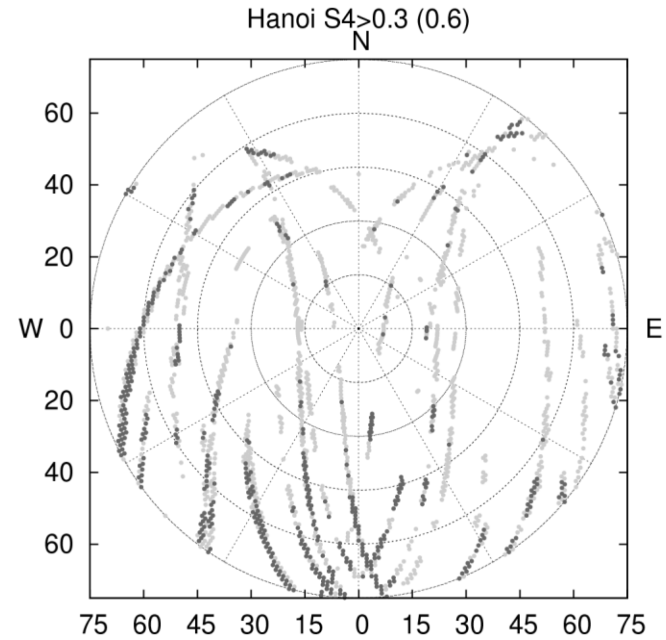




Spatial distribution of scintillating satellites



Peru, 6 months



Vietnam, 20 events

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Outlook

JRC work in progress on:

- **Impact of SW on the European power grid including consideration of interdependencies and economic impact**
- **Scintillation prediction and monitoring to understand the impact of SW on GNSS signal propagation and establish an event library for receiver testing**
- **Raising awareness of SW risk to CI sectors (in preparation: financial trading)**

From a risk management point of view further work is needed on:

- **Vulnerability and consequence analysis:** Which are system weaknesses with respect to SW? Are there aggravating factors (e.g. large-scale impact; interdependencies)?
- **Risk analysis:** What are realistic impact scenarios?
- **Risk reduction:** Which additional measures (prevention/mitigation) can be taken and how should their effectiveness be evaluated?
- **Etc.**

THANK YOU
FOR YOUR ATTENTION!

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